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Streamflow Forecasting for Blacksmith For River, Utah

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STREAMFLOW FORECASTING FOR BLACKSMITH FORK RIVER, UTAH

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES, Continued

LIST OF FIGURES

INTRODUCTION

PURPOSE

The method for streamflow forecasting by using Fourier Series and Multiple Regression as a mathematical model have been suggested and proved with high accuracy for the streamflow forecasting on Logan River, Utah by Professor Cleve H. Milligan and Dr. Rex L. Hurst. 1/

In this thesis the method is extended to the forecasting for the Blacksmith Fork River, south of the Logan River.

Because the climatological data are not available in the Blacksmith Fork watershed, this thesis also provides a technique for using the available data from adjacent watersheds.

OBJECTIVES

1. To forecast the streamflow on Blacksmith Fork River, Cache County, Utah by using Fourier Series and Multiple Regression as a mathematical model.
2. To test the consistency of the snow, temperature, precipitation, and streamflow data by statistical methods.
3. To test the significance of the variables considered in the mathematical model.

REVIEW OF LITERATURE

Streamflow has been predicted from the April 1 snow survey data of the drainage basin with a fair degree of accuracy, but for some years the April 1 snow survey data alone may not be a sufficiently reliable index of the streamflow in that area.

Numerous methods have been suggested in the search of a reliable forecasting equation and various other data have been used; but most

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1/ Unpublished progress report No. 2, Civil and Irrigation Engineering Department, Utah State University.

of these methods were based upon the percentage method or the method of seasonal percentages which was first indicated by Church (3) in 1935.

The general objectives of some of these researches have been to find a forecasting equation which would:

1. Minimize the number of the factors or variables considered in the equation -- i.e., the forecasting equation must be as simple as it can in order to minimize the computation work.
2. Consider only the designated variables measured in a given local area -- i.e., a formula which has in it variables which are not measured in the local area is not practical.
3. Utilize only April 1 snow survey data in the forecasting equation. Many of these equations neglect other important factors. Some researches have included factors other than the April 1 snow survey data. Some of these are summarized below:

1. Precipitation
   a. Monson (20) and Farrow (11) included fall rainfall as a factor.
   b. Paget (23), Church and Boardman (4), and Clyde and Work (6) included spring rainfall.
   c. Olsen and Price (22) included both Fall and Spring rainfall.
   d. Work, Wilm and Nelson (29) included April and first-half May rainfall.
   e. Chard (2) included Mid-March to June rainfall.

   All of these procedures are rather arbitrary.
2. Temperature
   a. Work (28) included temperature departure from normal as an index.

b. Koelzer (18) included cumulative temperature versus cumulative runoff as a correction factor.

c. Gay (14) and Johnson (16) suggested a forecast spring and summer temperature with other factors to predict streamflow.

3. Base flow

a. Eagle (9) included October runoff.

b. Parshall (25) included Fall runoff.

c. Peck (26) included February streamflow.

d. Nelson, McDonald and Barton (21) included November 1 or February 1 runoff.

e. Corps of Engineers, Portland, Oregon (7) included Winter flow.

4. Soil moisture or ground water

a. Elges (10) included water level in shallow well.

b. Clyde (5) and Clyde and Work (6) included soil-moisture.

5. Combination of factors

a. Paget (24) included soil-moisture and precipitation during the runoff period.

b. Fulcher (13) included precipitation, temperature and sub-basin analysis.

c. Bissell and Earls (1) included April-June precipitation and April-September base flow.

d. Hannaford (15) included October-March precipitation and April-July runoff of previous year and April-June precipitation.

Nearly all of the above researchers made some improvements in streamflow forecasting procedure; but in the attempt to minimize the number of variables the value of some available data was lost.

Consequently, the accuracy of some of these methods is probably not as high as it could have been. However, the error in neglecting these factors has not been determined.

Croft (8) indicated that the important factors which influence the accuracy of the streamflow forecasting are snow storage, precipitation, temperature, and soil-moisture; and his results show that these factors are interacting.

The multiple correlation analysis for streamflow forecasting was introduced by Ford (12) in 1948. Gay (14) also use multiple correlation analysis for temperature forecasting in 1952.

The method described in this thesis utilizes antecedent monthly precipitation, monthly temperature, monthly runoff and April 1 snow survey data in the forecasting procedure. Fourier coefficients are utilized to represent antecedent precipitation, temperature, and streamflow data. A mathematical model which is hereafter described is utilized to give an accurate, unbiased prediction of expected streamflow. Theoretically, the accuracy of this method can be increased by adding additional terms to the Fourier Series.

This method is statistically and physically sound and accuracy is improved, although the work of computation for finding the multiple regression coefficients is considerably increased. Modern high speed computing equipment, however, makes this additional computing rather easy to perform.

PROCEDURES

COLLECTION AND ARRANGEMENT OF DATA

1. The data collected for streamflow forecasting included:
   a. Snow survey data as published by the Soil Conservation Service, U. S. Department of Agriculture, in "Federal-State Cooperative Snow Surveys and Water Supply Forecasts for Utah."
   b. Temperature data as published by Weather Bureau, U. S. Department of Commerce in "Climatological Data for Utah."
   c. Precipitation data as published by Weather Bureau, U. S. Department of Commerce in "Climatological Data for Utah."
   d. Streamflow data as published by Geological Survey, U. S. Department of Interior in "Geological Survey Water-Supply Papers, Part 10. The Great Basin."
2. All of these data were tabulated by water year (Oct. 1 to Sept. 30).

THE STUDY OF THE CONSISTENCY OF THE COLLECTED DATA

The consistency of the collected data directly influences the accuracy of streamflow forecasts. A careful study was made to determine whether or not any changes were made in the location of measuring stations which would have an influence on the data.

1. Consistency of snow survey data.

Mt. Logan snow course and Franklin Basin snow course have continuous data for the study years (from 1924-1957). The snow course history shows that these two courses did not change their location since they were established. Minor changes were made, however, in the number of samples collected at these stations.

Data from these two dependable courses were plotted against data from the other courses, utilizing the double-mass curve method (18). The results are shown in Figure 1 to Figure 6. These figures indicate no radical inconsistencies except in the cases of Garden City Summit versus Franklin Basin and Monte Cristo versus Franklin Basin. In these cases missing data were replaced by linear regression studies in which the correlation coefficients were only fair.

Linear regression and correlation studies were also made; the results are listed in Table 13 to 16. In general there is a high degree of correlation between the snow courses.

2. Consistency of temperature data.

Temperature data collected at Logan, Utah were used in these studies, since this station has the longest consistent record.

3. Consistency of precipitation data.

The station history of Richmond, Utah for precipitation shows that this station has had no change of location since it was established, and its record is complete for the study years. A double-mass curve study with Richmond versus Logan was made. The result shows a straight line (Figure 7). No adjustment is needed.

4. Consistency of streamflow data.

The streamflow data of Blacksmith Fork River is complete for the study period. A double-mass curve study with Blacksmith Fork River versus Logan River was made. There are several minor bends in the curve (Figure 8). No corrections for changes in relationships were made, that is, it is assumed that the Blacksmith Fork record is consistent. The reasons for the bends in the double-mass curve are not known.

ESTIMATING MISSING SNOW COURSE DATA BY LINEAR CORRELATION AND REGRESSION STUDIES

There are four snow courses -- Tony Grove Lake, Monte Cristo, Dry Bread Pond, and Garden City Summit with some missing data for the study years. A linear correlation and regression study for each of these courses versus the reliable courses Mt. Logan and Franklin Basin was made. Among these two studies, the one with the higher correlation coefficient was chosen for estimating the missing data (See Tables 13-16). Mt. Logan was used for estimating missing data for Tony Grove Lake; Franklin Basin was used for estimating missing data for Monte Cristo, Dry Bread Pond, and Garden City Summit.

THE LINEAR CORRELATION STUDY OF THE SNOW, TEMPERATURE, PRECIPITATION, AND LOGAN RIVER STREAMFLOW VERSUS BLACKSMITH FORK RIVER'S STREAMFLOW

The purpose of this study is to determine which data will be best for streamflow forecasting. This was considered essential since the collected data are not measured within the Blacksmith Fork watershed, that is, data outside of the watershed had to be used in this study. The results of this study are summarized in Table 12. Details for Logan River versus Blacksmith Fork River are shown in Table 17.

DESCRIPTIONS OF THE MATHEMATICAL MODEL

1. Fourier Series

Fourier Series were used to fit temperature, precipitation, and streamflow data. Fourier Series may be expressed as,

$$f(x) = \frac{A_o}{2} + \sum_{1}^{\infty}\left(A_n \cos \frac{n\pi x}{c} + B_n \sin \frac{n\pi x}{c}\right) \quad \ldots\ldots\ldots (1)$$

Where A_n and B_n are Fourier coefficients defined as follows:

$$A_n = \frac{1}{c}\int_{-c}^{c} f(x) \cos \frac{n\pi x}{c} dx \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$B_n = \frac{1}{c}\int_{-c}^{c} f(x) \sin \frac{n\pi x}{c} dx \quad \ldots\ldots\ldots\ldots \quad (3)$$

A_o is the value of A_n when n is zero, or the mean value of the function c is in the interval over which f(x) is expressed, that is $-c \leqq x \leqq c$. f(x) can have only a finite number of finite discontinuities and maxima and minima over the interval c.

For purposes of this analysis equation (1) simply states that if f(x) represents actual temperature, precipitation, or streamflow data plotted on a time scale, we can fit a trigonometric curve of the form represented by the right-hand side of the equation to these data by an appropriate selection of the coefficients A_1, A_2, A_3, ... A_n and B_1, B_2, B_3, ... B_n. Procedure (27) for selection of these coefficients is indicated in equations (2) and (3). Examples of the numerical procedure will follow.

In this thesis equation (1) was simplified and utilized to represent monthly mean temperature, monthly precipitation, and monthly streamflow in time as follows:

a. Temperature

$$T_M = \bar{T} + A_{T1} \cos \theta + A_{T2} \sin \theta + A_{T3} \cos 2\theta + A_{T4} \sin 2\theta \ldots . \quad (4)$$

where, T_M = Mean temperature for any month of the year in question.

$\bar{T}$ = Average temperature for 12 months (mean of monthly mean temperatures).

A_{T1}, A_{T2}, A_{T3}, and A_{T4} are Fouriér coefficients determined from actual temperature data.

θ = Time (2π radians or 360 degrees is one year).

Only four terms of the series were considered necessary to represent monthly mean temperature adequately. The accuracy can be increased by adding additional terms to the series. This, however, increases the work of computation.

b. Precipitation:

$$P_M = \bar{P} + A_{P1} \cos \theta + A_{P2} \sin \theta + A_{P3} \cos 2\theta + A_{P4} \sin 2\theta \ . \ . \quad (5)$$

where, P_M = Mean precipitation for any month of the year in question

$\bar{P}$ = Average precipitation for 12 months (based on a water year).

A_{P1}, A_{P2}, A_{P3}, and A_{P4} are Fourier coefficients determined from actual precipitation data.

θ = time (2π radians or 360 degrees is one year).

c. Streamflow:

$$F_M = \bar{F} + A_{F1} \cos \theta + A_{F2} \sin \theta + A_{F3} \cos 2\theta + A_{F4} \sin 2\theta \ . \ . \quad (6)$$

where, F_M = Mean streamflow for any month of the year in question.

$\bar{F}$ = Average streamflow for 12 months (based on a water year).

A_{F1}, A_{F2}, A_{F3}, and A_{F4} are Fourier coefficients determined from actual streamflow data. 1/

θ = time (2π radians or 360 degrees is one year).

1/ Examples of the procedure for the numerical computation of the Fourier coefficients for temperature, precipitation, and stream flow data are in Tables 3-5 of the Appendix (17).

2. The streamflow forecasting equation.

The streamflow forecasting equation, using water content of the April 1 snow cover as indicated by the seven snow courses and the means and Fourier coefficients from equations (4), (5), and (6), is as follows:

$$\begin{aligned}\hat{Y} = {} & b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 \\ & + b_8\bar{T} + b_9A_{T_1} + b_{10}A_{T_2} + b_{11}A_{T_3} + b_{12}A_{T_4} \\ & + b_{13}\bar{P} + b_{14}A_{P_1} + b_{15}A_{P_2} + b_{16}A_{P_3} + b_{17}A_{P_4} \\ & + b_{18}\bar{F} + b_{19}A_{F_1} + b_{20}A_{F_2} + b_{21}A_{F_3} + b_{22}A_{F_4} \quad \ldots\ldots\ldots \quad (7)\end{aligned}$$

where, $\hat{Y}$ = the predicted monthly streamflow.

b_o = A constant. (Y-axis intercept)

b_1, b_2, b_3, ... b_{22} are the multiple regression coefficients.

x_1, x_2, x_3 ... x_7 are the April 1 measurements of the water content of the snow courses listed hereafter.

3. Simultaneous equations for determination of the multiple regression coefficients.

$$\left.\begin{aligned}& b_oN + b_1\Sigma x_1 + b_2\Sigma x_2 + b_3\Sigma x_3 + \ldots\ldots\ldots + b_{21}\Sigma A_{F_3} + b_{22}\Sigma A_{F_4} = \Sigma Y \\ & b_o\Sigma x_1 + b_1\Sigma x_1^2 + b_2\Sigma x_1x_2 + b_3\Sigma x_1x_3 + \ldots\ldots + b_{22}\Sigma x_1A_{F_4} = \Sigma x_1Y \\ & b_o\Sigma x_2 + b_1\Sigma x_2x_1 + b_2\Sigma x_2^2 + \ldots\ldots\ldots\ldots + b_{22}\Sigma x_2A_{F_4} = \Sigma x_2Y \\ & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & b_o\Sigma A_{F_3} + b_1\Sigma A_{F_3}x_1 + b_2\Sigma A_{F_3}x_2 + \ldots + b_{21}\Sigma A_{F_3}^2 + b_{22}\Sigma A_{F_3}A_{F_4} = \Sigma A_{F_3}Y \\ & b_o\Sigma A_{F_4} + b_1\Sigma A_{F_4}x_1 + b_2\Sigma A_{F_4}x_2 + \ldots + b_{21}\Sigma A_{F_4}A_{F_3} + b_{22}\Sigma A_{F_4}^2 = \Sigma A_{F_4}Y\end{aligned}\right] \quad (8)$$

where, N = the number of years in this study. (that is, the number of observations).

Y = the measured monthly streamflow in question.

For more detail explanation of the meanings denoted by the symbols in the streamflow forecasting equation and the simultaneous equations, the following tabulation is included:

Snow Courses (the April 1 snow water content data)

x_1 = Franklin Basin

x_2 = Mount Logan

x_3 = Tony Grove Lake

x_4 = Monte Cristo

x_5 = Dry bread pond

x_6 = Garden City Summit

x_7 = Spring Hollow Upper

Temperature (Logan, Utah)

$\bar{T}$ = Average temperature for 12 months, in F° (based on a water year).

$A_{T1} = \frac{1}{6} (\Sigma X_T \cos\theta)$

$A_{T2} = \frac{1}{6} (\Sigma X_T \sin\theta)$

$A_{T3} = \frac{1}{6} (\Sigma X_T \cos 2\theta)$

$A_{T4} = \frac{1}{6} (\Sigma X_T \sin 2\theta)$

where, X_T = Monthly mean temperature for the month in question. Derivation of these equations is shown in reference 17 of the literature cited.

Precipitation (Richmond, Utah)

$\bar{P}$ = Average precipitation for 12 months, in inches (based on a water year)

$A_{P_1} = \frac{1}{6} (\Sigma X_P \cos\theta)$

$A_{P_2} = \frac{1}{6} (\Sigma X_P \sin\theta)$

$A_{P3} = \frac{1}{6} (\Sigma X_P \cos 2\theta)$

$A_{P4} = \frac{1}{6} (\Sigma X_P \sin 2\theta)$

where, X_P = Monthly precipitation for the month in question.

Streamflow (Blacksmith Fork River, Utah)

$\bar{F}$ = Average streamflow for 12 months, in acre-feet (based on a water year).

$A_{F1} = \frac{1}{6} (\Sigma X_F \cos\theta)$

$A_{F2} = \frac{1}{6} (\Sigma X_F \sin\theta)$

$A_{F3} = \frac{1}{6} (\Sigma X_F \cos 2\theta)$

$A_{F4} = \frac{1}{6} (\Sigma X_F \sin 2\theta)$

where, X_F = Monthly streamflow for the month in question

THE SOLUTION

A matrix for determining the multiple regression coefficients — "b" values of the streamflow forecasting equation is set up from the simultaneous equations 8. The data for each variable is available for thirty-four years (1924-1957). Code factors were used to code the data of each variable to make handling of the matrix easier. IBM machines were used in the solution of the 22 simultaneous equations which involved the inversion of a 22-order matrix. See Table (11) for values of the b_n, Table (10) for decode factors and Table (10) for the value of b_o.

EXAMPLE OF APPLICATION

An example for prediction of the streamflow by this method is in the following: (In this example actual measured data for the October-March as well as the April-September periods were used. In an actual prediction data are not available for the April-September period, in which case the long-time monthly means are used).

To find the forecasted streamflow of Blacksmith Fork River for May, 1955:

Variables	Uncode value	Code* factor	Coded x"	b_n	$x''b_n$
Snow					
x_1 : Franklin Basin	23.8	1/10	2.38	+0.470305	+1.11932672
x_2 : Mt. Logan	27.6	1/10	2.76	+0.902920	+2.49205865
x_3 : Tony Grove Lake	32.5	1/10	3.25	-0.332077	-1.07924969
x_4 : Monte Cristo	26.9	1/10	2.69	+0.593176	+1.59564395
x_5 : Dry Bread Pond	20.1	1/10	2.01	+0.050502	+0.10150878
x_6 : Garden City	14.6	1/10	1.46	-0.383919	-0.56052145
x_7 : Spring Hollow U.	23.3	1/10	2.33	-0.372957	-0.86898976
Temperature					
$\bar{T}$	46.5	1/10	4.65	-0.654016	-3.04117245
$^{A}T_1$	7.4	1	7.4	-0.037080	-0.27439548
$^{A}T_2$	2.9	1	2.9	-0.083175	-0.24120892
$^{A}T_3$	4.5	1	4.5	-0.035155	-0.15819813
$^{A}T_4$	6.2	1	6.2	+0.021939	+0.13602608
Precipitation					
$\bar{P}$	1.57	10	15.7	+0.040357	+0.63360694
$^{A}P_1$	0.76	10	7.6	-0.079953	-0.60764227
$^{A}P_2$	1.27	10	12.7	+0.060833	+0.77257834
$^{A}P_3$	0.27	10	2.7	+0.047206	+0.12745531
$^{A}P_4$	0.78	10	7.8	-0.065737	-0.51274829
Streamflow					
$\bar{F}$	5800.00	1/1000	5.8	+0.017933	+0.10401310
$^{A}F_1$	6670.00	1/1000	6.67	+0.349301	+2.32983940
$^{A}F_2$	5520.00	1/1000	5.52	-0.615137	-3.39555635
$^{A}F_3$	1390.00	1/1000	1.39	+0.325076	+0.45185582
$^{A}F_4$	830.00	1/1000	0.83	-0.462096	-0.38353952
					$\Sigma x''b_n = -1.25930922$

$$\hat{Y} = (b_0 + \Sigma b_n x'')10000 = (2.98590103 - 1.25930922)\ 10^4 = 17{,}266 \text{ acre-ft.}$$

* Here the code factor for each variable was used to facilitate handling the information matrix in the matrix inversion process.

Data used in the illustrated example are found in tables as listed:

Table (6), snow course data for 1955.

Table (7), temperature data for 1955.*

Table (8), precipitation data for 1955.*

Table (9), streamflow data for 1955.*

Table (10), b_o and decode factor for May.

Table (11), b_n for May.

A TEST OF THE SIGNIFICANCE FOR THE VARIABLES USED IN THE MATHEMATICAL MODEL

1. The analysis of variance of the multiple regression model.

   An analysis of variance of the multiple regression model of the snow, temperature, precipitation, and streamflow was carried on a monthly basis. The purpose of this study is to compute the significant influence of each of these four different types of data.

   The detailed results of these studies are listed in Tables (18) and (19).

2. The analysis of variance for the individual variables considered in the forecasting equation.

   This study provided more detailed information on the significant importance of the individual variables considered in the forecasting equation.

   The results of these studies are listed in Table (20).

* The data are actually the antecedent temperature, precipitation and streamflow beginning with October, 1954 for the preceding year and the monthly mean temperature, precipitation, and streamflow for the months subsequent to the April 1 predicition date. The data were arranged in the tables for the current year (1955).

RESULTS AND DISCUSSION

Analysis of the streamflow forecasting results shows that this forecasting method has a high accuracy in the thirty-four years of record (Table 1).

Table 1. Accuracy of Monthly Forecasts Summarized for 408 Months of Record (1924-1957)

Percent Accuracy	Months	Percent of Total Months
100	26	6.36
99	70	17.15
98	113	27.68
97	144	35.30
96	173	42.40
95	201	49.20
94	234	57.35
93	258	63.20
92	268	65.65
91	284	69.55
90	297	72.75
89	310	76.00
88	321	78.65
87	337	82.55
86	351	86.00
85	355	87.00
80	373	91.40
75	386	94.60
70	392	96.00

Table 2. Comparison of forecasts made by methods described herein with published forecasts for the April-September streamflow.

Year	Actual Flow (A.F.)	Proposed Method Runoff (A.F.)	Proposed Method %Error	Published Forecasts Runoff (A.F.)	Published Forecasts %Error
1935	35,640	29,522	-17.17	35,600	- 0.01
1936	89,990	86,688	- 3.67	90,000	- 0.01
1937	58,580	46,890	-19.96	58,600	- 0.03
1938	59,410	57,691	- 2.89	80,000	+34.66
1939	33,750	34,090	+ 1.01	45,000	+33.33
1940	23,870	33,280	+39.42	30,000	+25.68
1941	20,800	24,001	+15.39	30,000	+44.23
1942	28,580	36,891	+29.08	28,600	+ 0.01
1943	62,030	64,638	+ 4.20	75,000	+20.91
1944	35,250	27,524	-21.92	27,000	-23.40
1945	48,250	44,734	- 7.29	40,000	-17.10
1946	92,440	94,481	+ 2.21	64,000	-30.76
1947	30,360	39,730	+30.86	40,000	+31.75
1948	73,570	64,379	-12.49	46,000	-37.47
1949	64,740	74,633	+15.28	62,000	- 4.23
1950	103,090	98,121	- 4.82	75,000	-27.25
1951	93,180	88,703	- 4.80	67,500	-27.56
1952	108,780	105,070	- 3.41	100,000	- 8.07
1953	50,540	57,552	+13.87	32,000	-36.68
1954	38,880	41,055	+ 5.59	50,000	+28.60
1955	45,670	49,763	+ 8.75	53,000	+15.82
1956	72,660	67,500	- 7.10	70,000	- 3.66
1957	67,800	64,477	- 4.90	58,000	-14.45

Analysis of variance shows that the antecedent streamflow data are highly significant for all months except May and June (Table 18). The snow data are also highly significant for all months except October and November in which the significance is lower. Temperature data are relatively significant for the months of October, January, February, and March. These months are in the low runoff- period of Blacksmith Fork River. Precipitation data are relatively significant for the months of April, May, July, August, and September. These months are in the high runoff-period of Blacksmith Fork River.

The analysis of variance indicates that the significance of the individual variable changes with different months; but no one variable can be identified as a completely unnecessary variable in the forecasting equation (Table 20).

CONCLUSION

1. The method for streamflow forecasting by using Fourier Series and Multiple Regression as a mathematical model is applicable to streamflow forecasting for the Blacksmith Fork River with improved accuracy over previous forecasts.
2. Results indicate that even though a watershed has no available weather and snow survey data within its own boundaries a reliable streamflow forecast can be made for most years by using data from an adjacent watershed.
3. Results of the analysis of variance of the multiple regression model shows that the antecedent streamflow is an important factor in forecasting future streamflow. This factor is of less importance during the months of high runoff of Blacksmith Fork River -- May and June, snow water content is the important factor in these two months.
4. Although temperature showed a lower degree of significance in the forecasting equation, it was of more significance in the low run-off period of Blacksmith Fork River. Rainfall in general also shows a lower degree of significance in the forecast equation, but it showed increased significance in the high runoff-period of Blacksmith Fork River.
5. Probably the accuracy of forecasts could be improved if snow survey data were collected within the watershed boundary.

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APPENDIX

Table 3 . Example for computation of Fourier temperature coefficient.--1954
(Temperature at Logan, Utah)

Mo.	x*	(A_{T1}) cosθ	Coeff. cosθ xcosθ	(A_{T2}) of sinθ	Coeff. sinθ xsinθ	(A_{T3}) of cos2θ	Coeff. cos2θ xcos2θ	(A_{T4}) of sin2θ	Coeff. $\sin\frac{\theta}{2}$ $x\sin\frac{\theta}{2}$
Oct.	52.2	1.000	52.20	0.000	0	1.000	52.20	0.000	0
Nov.	42.7	0.866	36.98	0.500	21.35	0.500	21.35	0.866	36.98
Dec.	27.3	0.500	13.65	0.866	23.64	-0.500	-13.65	0.866	23.64
Jan.	29.7	0.000	0	1.000	29.70	-1.000	-29.70	0.000	0
Feb.	30.8	-0.500	-15.40	0.866	26.67	-0.500	-15.40	-0.866	-26.67
Mar.	36.6	-0.866	-31.70	0.500	18.30	0.500	18.30	-0.866	-31.70
Apr.	52.2	-1.000	-52.20	0.000	0	1.000	52.20	0.000	0
May	59.2	-0.866	-51.27	-0.500	-29.60	0.500	29.60	0.866	51.27
June	61.1	-0.500	-30.55	-0.866	-52.91	-0.500	-30.55	0.866	52.91
July	74.1	0.000	0	-1.000	-74.10	-1.000	-74.10	0.000	0
Aug.	69.6	0.500	34.80	-0.866	-60.27	-0.500	-34.80	-0.866	-60.27
Sept.	62.5	0.866	54.13	-0.500	-31.25	0.500	31.25	-0.866	- 54.13
Sum			+10.64		-128.47		+ 6.70		- 7.97
A_T			+ 1.77		- 21.41		+ 1.12		- 1.33
Code factor ** for A_T			+ 1.54		+ 27.81		+ 2.23		+ 5.34
Coded A_T ***			+ 3.3		+ 6.4		+ 3.3		+ 4.0

* The x values are the current year monthly mean temperature beginning from October, 1953 to September, 1954.

** According to the limitations of the IBM machines, no negative value will be presented in the information matrix for matrix inversion; so that the maximum negative value of each variable was chosen as the code factor by change the sign to positive in order to code all the values of that variable to positive.

*** Coded A_T = Code factor + A_T.
This example is similar to an example in unpublished progress report No. 2 referred to on page 1.

Table 4. Example for computation of Fourier precipitation coefficients--1954
(Precipitation at Richmond, Utah)

Mo.	x*	(Ap_1) of $\cos\theta$	Coeff. $\cos\theta$ $x\cos\theta$	(Ap_2) of $\sin\theta$	Coeff. $\sin\theta$ $x\sin\theta$	(Ap_3) of $\cos2\theta$	Coeff. $\cos2\theta$ $x\cos2\theta$	(Ap_4) of $\sin2\theta$	Coeff. $\sin2\theta$ $x\sin2\theta$
Oct.	0.76	1.000	0.76	0.000	0	1.000	0.76	0.000	0
Nov.	0.74	0.866	0.64	0.500	0.37	0.500	0.37	0.866	0.64
Dec.	1.18	0.500	0.59	0.866	1.02	-0.500	-0.59	0.866	1.02
Jan.	1.68	0.000	0	1.000	1.68	-1.000	-1.68	0.000	0
Feb.	0.80	-0.500	-0.40	0.866	0.69	-0.500	-0.40	-0.866	-0.69
Mar.	2.85	-0.866	-2.47	0.500	1.42	0.500	1.42	-0.866	-2.47
Apr.	0.91	-1.000	-0.91	0.000	0	1.000	0.91	0.000	0
May	0.79	-0.866	-0.68	-0.500	-0.40	0.500	0.40	0.866	0.68
June	2.00	-0.500	-1.00	-0.866	-1.73	-0.500	-1.00	0.866	1.73
July	0.59	0.000	0	-1.000	-0.59	-1.000	-0.59	0.000	0
Aug.	0.25	0.500	0.13	-0.866	-0.22	-0.500	-0.13	-0.866	-0.22
Sept.	1.73	0.866	1.50	-0.500	-0.86	0.500	0.86	-0.866	-1.50
Sum			-1.84		-1.38		0.33		-0.81
Ap			-0.307		0.23		0.055		-0.135
Code factor for Ap **			+0.994		+0.611		+0.358		+0.70
Coded Ap ***			0.69		0.84		0.41		0.57

* The x values are the current year monthly precipitation beginning from October, 1953 to September, 1954.

** According to the limitations of the IBM machines, no negative will permit into the information matrix for matrix inversion; so the maximum negative value of each variable was chosen as the code factor by change the sign to positive in order to code all the values of that variable in positive.

*** Coded Ap = Ap + Code factor.

Table 5. Example for computation of Fourier streamflow coefficients ---1954

(Streamflow on Blacksmith Fork River, Utah)

Mo.	X*	(A_{F_1}) of cosθ	Coeff. cosθ xcosθ	(A_{F_2}) of sinθ	Coeff. sinθ xsinθ	(A_{F_3}) of cos2θ	Coeff. cos2θ xcos2θ	(A_{F_4}) of sin2θ	Coeff. sin2θ xsin2θ
Oct.	8,150	1.000	8,150	0.000	0	1.000	8,150	0.000	0
Nov.	7,150	0.866	6,192	0.500	3,575	0.500	3,575	0.866	6,192
Dec.	6,670	0.500	3,335	0.866	5,776	-0.500	-3,335	0.866	5,776
Jan.	6,510	0.000	0	1.000	6,510	-1.000	-6,510	0.000	0
Feb.	5,510	-0.500	-2,755	0.866	4,772	-0.500	-2,755	-0.866	-4,772
Mar.	6,430	-0.866	-5,568	0.500	3,215	0.500	3,215	-0.866	-5,568
Apr.	8,740	-1.000	-8,740	0.000	0	1.000	8,740	0.000	0
May	11,260	-0.866	-9,751	-0.500	-5,630	0.500	5,630	0.866	9,751
June	11,040	-0.500	-5,520	-0.866	-9,561	-0.500	-5,520	0.866	9,561
July	7,470	0.000	0	-1.000	-7,470	-1.000	-7,470	0.000	0
Aug.	6,400	0.500	3,200	-0.866	-5,542	-0.500	-3,200	-0.866	-5,542
Sept.	5,630	0.866	4,876	-0.500	-2,815	0.500	2,815	-0.866	-4,876
Sum			-6,581		-7,170		+3,335		+10,522
A_F			-1,097		-1,195		+ 556		+1,754
Code factor** for A_F			+8,176		+5,851		+ 166		
Coded A_F***			+7,080		+4,660		+ 720		+1,750

* The X values are the antecedent year monthly streamflow beginning from October, 1952 to September, 1953.

** According to the limitations of the IBM machines, no negative value will be presented in the information matrix for matrix inversion; so that the maximum negative value of each variable was chosen as the code factor by changing the sign to positive in order to code all the values of that variable to positive.

*** Coded A_F = A_F + Code Factor

Table 6 . April 1 Water content of snow at seven snow courses (inches)

Year	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1924	25.1	25.8	31.8	23.2	17.2	17.8	21.8
1925	28.3	32.1	35.5	25.7	19.2	20.3	27.3
1926	18.4	22.0	21.9	17.8	13.1	12.5	17.6
1927	33.8	40.8	43.5	30.1	22.6	24.6	31.5
1928	30.0	31.6	34.9	27.1	20.3	21.6	23.3
1929	31.1	35.0	41.7	21.7	20.9	22.5	28.9
1930	26.8	28.5	31.5	14.6	18.3	19.1	20.7
1931	14.9	13.4	14.9	6.5	10.9	4.4	10.0
1932	38.6	42.3	54.2	20.2	25.6	24.6	36.5
1933	28.2	28.4	38.4	19.4	19.1	18.2	25.4
1934	12.6	18.8	19.2	7.0	9.5	4.3	12.4
1935	24.4	27.9	29.1	16.4	16.8	17.9	28.9
1936	39.7	38.3	50.5	39.6	22.1	33.9	34.8
1937	20.8	27.4	32.5	18.8	13.3	18.5	25.0
1938	24.9	27.5	36.5	30.7	23.6	20.4	21.9
1939	20.4	20.8	25.2	20.3	11.5	16.7	19.4
1940	21.8	23.5	27.0	17.6	10.7	12.6	20.5
1941	15.6	19.4	21.7	16.4	11.6	12.8	18.4
1942	17.8	22.5	23.3	18.2	12.7	14.1	21.4
1943	38.8	41.3	54.9	32.7	26.1	30.5	35.8
1944	20.2	17.8	20.5	18.3	12.9	15.6	16.8
1945	19.8	22.8	27.3	23.9	18.0	15.5	20.2
1946	30.2	36.1	37.4	30.6	18.7	26.1	30.0
1947	23.3	21.0	28.0	24.0	16.0	16.0	18.8
1948	26.5	26.4	30.9	22.0	18.1	15.4	22.0

Table 6 . April 1 Water content of snow at seven snow courses (inches) (Continued)

Year	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1949	30.5	34.6	41.3	31.1	22.8	22.8	31.0
1950	41.3	41.9	50.3	36.0	27.0	28.9	34.7
1951	32.8	37.4	52.0	31.4	21.1	24.4	30.4
1952	40.2	43.8	47.6	39.2	31.3	26.6	34.6
1953	23.7	26.0	35.5	23.4	16.2	14.5	22.3
1954	23.3	27.9	27.5	22.3	14.7	19.5	24.1
1955	23.8	27.6	32.5	26.9	20.1	14.6	23.3
1956	31.8	34.8	41.6	31.6	20.3	20.7	21.5
1957	31.6	30.5	36.1	25.7	19.0	21.3	28.1
Code factor	1/10	1/10	1/10	1/10	1/10	1/10	1/10

Table 7 . Logan annual monthly mean temperature and Fourier coefficients ---coded:

Year	$\bar{T}$ (F°)	A_{T1} (1.54)	A_{T2} (+27.81)	A_{T3} (+2.23)	A_{T4} (+5.34)
1924	47.5	1.7	4.7	1.5	4.0
1925	47.5	0	5.1	3.5	1.8
1926	49.3	0.6	6.5	1.7	3.5
1927	48.6	3.1	7.2	1.7	3.5
1928	49.2	2.8	6.4	3.4	2.9
1929	46.9	4.0	3.5	2.6	3.6
1930	48.8	1.8	6.0	2.8	2.6
1931	47.7	1.1	0	1.9	1.7
1932	46.1	3.2	0.9	4.1	2.2
1933	46.9	4.8	1.0	1.7	4.7
1934	53.8	0.4	8.2	2.6	2.6
1935	49.8	5.6	4.5	1.9	2.9
1936	49.7	1.7	2.9	1.5	4.0
1937	47.6	5.1	1.1	4.1	3.7
1938	50.8	5.1	7.5	1.8	2.6
1939	48.8	2.8	3.8	2.9	3.7
1940	52.5	2.3	5.6	1.3	3.9
1941	48.4	1.8	5.4	2.3	3.2
1942	46.5	5.4	2.0	2.4	4.6
1943	49.2	3.5	5.2	3.4	2.2
1944	47.3	5.1	4.4	3.9	3.9
1945	47.2	3.5	5.8	2.0	1.9
1946	48.6	2.2	3.6	3.2	2.0
1947	48.3	1.8	5.3	2.2	2.9

Table 7 . Logan annual monthly mean temperature and Fourier coefficients---coded (Continued.)

Year	$\bar{T}$ (F°)	A_{T1} (1.54)	A_{T2} (+27.81)	A_{T3} (+2.23)	A_{T4} (+5.34)
1948	47.2	4.1	3.6	2.1	2.5
1949	46.8	2.7	0.7	7.4	2.0
1950	47.1	4.0	6.7	2.0	3.4
1951	48.7	5.2	6.7	3.0	4.4
1952	46.7	4.4	1.5	2.5	4.1
1953	49.8	4.8	7.3	0	0
1954	49.8	3.3	6.4	3.3	4.0
1955	46.5	7.4	2.9	4.5	6.2
1956	48.6	3.3	4.4	1.9	4.7
1957	47.7	1.9	4.1	2.1	0.8
code factor	1/10	1	1	1	1
	49.83	1.55	-21.41	1.12	-1.33

Table 8 . Richmond annual monthly mean precipitation and Fourier coefficients---coded

Year	$\bar{P}$ inches	A_{P1} (+0.994)	A_{P2} (+0.611)	A_{P3} (0.358)	A_{P4} (+0.70)
1924	1.03	1.01	1.15	0.82	0.56
1925	1.90	1.15	0.77	0.59	1.02
1926	1.45	0.88	0.91	0.38	0.79
1927	1.58	0.63	0.92	0.88	0.87
1928	1.27	0.69	0.88	0.86	1.20
1929	1.53	1.13	1.01	0.80	0.37
1930	1.55	0.71	0.64	0.48	0.17
1931	0.98	1.04	0.67	1.02	0.72
1932	2.08	0.04	1.18	0.49	0.86
1933	1.28	0.54	1.35	0.65	1.20
1934	0.92	0.97	1.30	0.21	0.55
1935	1.31	0.58	1.17	1.31	1.13
1936	1.54	0.47	1.59	0	0.51
1937	1.75	0.50	1.19	0.78	0.47
1938	1.57	0.44	1.40	0.98	1.02
1939	1.50	1.25	1.07	0.64	0.95
1940	1.36	0.68	1.32	0.34	0
1941	1.74	0.79	0.78	0.77	0.65
1942	1.79	1.02	1.43	0.76	1.45
1943	1.49	0.78	0.95	0.48	1.50
1944	1.05	1.08	0.91	0.61	0.77
1945	1.63	0.11	0	0.28	0.73
1946	1.79	1.06	0.94	1.31	1.37

Table 8 . Richmond annual monthly mean precipitation and Fourier coefficients--coded (Continued)

Year	$\overline{P}$ inches	A_{P1} (+0.994)	A_{P2} (+0.611)	A_{P3} (0.358)	A_{P4} (+0.70)
1947	1.97	1.05	0.37	1.31	1.39
1948	1.70	0.31	0.70	1.18	1.40
1949	1.68	0.59	1.39	0.36	1.63
1950	1.95	0.98	1.07	0.91	1.20
1951	1.76	1.06	0.68	0.38	0.60
1952	1.80	0.98	1.40	0.44	1.18
1953	1.24	0	1.11	0.24	1.12
1954	1.19	0.69	0.84	0.41	0.57
1955	1.57	0.76	1.27	0.27	0.78
1956	1.61	0.89	1.37	0.39	2.14
1957	1.60	0.06	0.78	1.09	0.85
Code factor	**10**	**10**	**10**	**10**	**10**

Table 9 . Blacksmith Fork River annual monthly mean streamflow and Fourier coefficients --coded

Year	$\bar{F}$ Acre-feet	A_{F1} (+8176)	A_{F2} (+5851)	A_{F3} (+166)	A_{F4}
1924	11,500	2,500	370	2,870	5,540
1925	7,800	6,290	5,000	2,180	1,940
1926	7,300	5,040	3,890	2,080	1,890
1927	5,600	6,940	5,400	1,360	710
1928	7,300	4,400	2,790	2,020	2,590
1929	7,600	4,740	3,750	2,360	2,050
1930	7,400	5,040	3,070	1,960	2,670
1931	5,600	7,270	5,120	1,170	660
1932	3,600	8,110	5,970	580	410
1933	8,500	1,330	560	3,360	4,230
1934	6,200	6,350	3,550	910	2,240
1935	3,500	8,260	6,400	590	360
1936	4,400	6,050	4,260	1,090	1,360
1937	9,200	0	680	4,960	4,720
1938	7,200	4,830	3,040	1,940	3,150
1939	7,400	4,470	3,560	2,500	1,880
1940	5,300	6,840	5,750	1,520	780
1941	3,800	7,370	5,830	780	430
1942	3,200	7,590	5,600	500	440
1943	3,800	6,980	4,860	740	700
1944	7,100	3,290	3,260	3,020	1,330
1945	5,100	7,360	4,760	580	1,230
1946	6,000	6,480	2,950	0	1,790

Table 9 . Blacksmith Fork River annual monthly mean streamflow and Fourier coefficients --coded (Continued)

Year	$\bar{F}$ Acre-feet	A_{F1} (+8176)	A_{F2} (+5851)	A_{F3} (+166)	A_{F4}
1947	10,400	420	2,200	5,370	2,620
1948	4,800	7,850	5,370	770	520
1949	8,500	3,590	1,660	2,250	3,740
1950	8,200	4,560	3,470	2,550	1,710
1951	12,300	1,260	60	4,570	4,080
1952	10,700	2,820	2,080	2,210	3,350
1953	12,300	1,040	0	4,210	5,340
1954	7,600	7,080	4,660	720	1,750
1955	5,800	6,670	5,520	1,390	830
1956	5,800	5,910	3,870	1,170	1,890
1957	9,000	3,040	3,610	2,330	2,110
Code factor	1/1000	1/1000	1/1000	1/1000	1/1000

Table 10 . The "b_o" value and decode factor for each month:

	October	November	December	January
b_o	9.70974910	5.97388320	1.730799410	8.78399410
Decode Factor	1,000	1,000	1,000	1,000

	February	March	April	May
b_o	5.62012795	1.70766534	43.99856074	2.98590103
Decode Factor	1,000	1,000	1,000	10,000

	June	July	August	September
b_o	39.34474401	14.71575340	11.63493168	12.11367090
Decode Factor	1,000	1,000	1,000	1,000

Predicted streamflow for each month is computed by the equation

$$\hat{Y} = (b_o + \Sigma\, b_n\, x'') \times \text{decode factor.}$$

Table 11 . The "b_n" values for each month:

Month	October	November	December	January
b_1	+1.27436331	+0.64680470	+0.61305491	+0.82658837
b_2	+0.29806575	+0.54662310	+1.33497180	+1.45181865
b_3	-0.50319263	-0.24974159	+0.20392499	+0.30572124
b_4	+0.40337716	+0.28069278	+0.00939006	+0.50398909
b_5	-0.50475502	-0.58955606	-1.51719999	-2.05234734
b_6	-0.86577407	-0.30131907	+0.54905062	-0.25822057
b_7	-0.21646264	-0.45883641	-2.12589477	-1.85262337
b_8	-1.86167551	-1.04258101	-0.56946103	-1.94277937
b_9	+0.05697393	+0.07485618	+0.13288413	+0.12760870
b_{10}	+0.07863214	+0.04536894	+0.01670219	+0.08430472
b_{11}	+0.00158779	+0.05761359	+0.03342968	+0.00683523
b_{12}	-0.09932425	-0.07789690	-0.02184902	-0.08536439
b_{13}	+0.00080199	-0.00024204	+0.03297562	-0.01841714
b_{14}	+0.01949332	+0.00235192	-0.00436091	+0.00811354
b_{15}	+0.02095804	-0.00182677	-0.00279782	+0.02557988
b_{16}	+0.01369946	+0.02024829	-0.00933643	-0.00213211
b_{17}	-0.03746928	-0.03040040	+0.05132175	+0.04795379
b_{18}	+0.55394388	+0.50440100	+0.63586947	+0.49129465
b_{19}	+0.36257497	+0.25754957	+0.06539179	+0.03813583
b_{20}	-0.50182951	-0.34771884	+0.16946736	+0.20743345
b_{21}	-0.07427239	-0.12420566	-0.43198475	-0.40996415
b_{22}	-0.01625951	-0.02205136	+0.19342615	+0.24610664

Table 11 . The "b_n"values for each month: (Continued)

Month	February	March	April	May
b_1	+1.53785412	+1.60328902	-2.29467104	+0.47030535
b_2	+0.35134489	+0.97533444	+3.63927218	+0.90291980
b_3	+0.41774143	+0.68873715	+1.48951172	-0.33207683
b_4	+0.45254908	+0.63184693	+2.76498707	+0.59317619
b_5	-1.77164943	-2.59497828	-1.88527156	+0.05050188
b_6	-0.82454060	+0.42613050	+5.49941704	-0.38391880
b_7	-0.97942624	-2.57361804	-3.72025578	-0.37295698
b_8	-1.25904937	+0.15454380	+7.74171235	-0.65401558
b_9	+0.12176066	+0.18042795	-0.11817717	-0.03708047
b_{10}	+0.12492331	+0.09797309	-0.79473922	-0.08317549
b_{11}	+0.12648130	+0.35625184	-0.16101856	-0.03515514
b_{12}	-0.03887361	-0.37255111	-0.42863501	+0.02193969
b_{13}	+0.02156406	+0.07683250	+0.58500584	+0.04035713
b_{14}	+0.00356600	+0.05597789	+0.08837335	-0.07995293
b_{15}	-0.03987551	-0.01053320	+0.37492805	+0.06083294
b_{16}	+0.01625126	+0.08322541	+0.27130345	+0.04720567
b_{17}	+0.00569198	+0.03767146	-0.04081323	-0.06573696
b_{18}	+0.38175239	+0.33539557	+1.62299508	+0.01793330
b_{19}	-0.05591129	-0.19040980	+3.00955315	+0.34930126
b_{20}	+0.19688068	+0.37747519	-5.69938752	-0.61513702
b_{21}	-0.51770559	-0.77523818	-0.66477538	+0.32507613
b_{22}	+0.32781023	+0.54328762	-4.33608438	-0.46209581

Table 11 . The "b_n" values for each month: (Continued)

Month	June	July	August	September
b_1	+4.93608518	+2.44948305	+1.53454913	+1.53832293
b_2	+1.89017086	+1.50678531	+1.52926776	+1.12934419
b_3	-1.48402255	-0.59262891	-0.46792756	-0.35547296
b_4	+2.66117702	+1.35538551	+0.86653436	+0.98262919
b_5	-1.73902440	-0.95177180	-0.22757637	-0.55898879
b_6	-5.16882156	-1.73217084	-1.00725993	-1.19965062
b_7	+1.16488613	-0.70531938	-0.96224164	-0.60380052
b_8	-6.37110316	-2.55059317	-1.85199532	-2.33219644
b_9	+0.51541420	+0.23397046	+0.12877585	+0.09580972
b_{10}	+0.18308097	+0.04016857	+0.04284644	+0.09054344
b_{11}	-0.39998851	-0.01407346	+0.02591300	+0.03287691
b_{12}	-0.62311077	-0.26550106	-0.11337127	-0.14808766
b_{13}	+0.28523553	+0.18872654	+0.14468711	+0.10342906
b_{14}	-0.07255229	-0.05789433	-0.09288032	-0.03165481
b_{15}	-0.05176043	+0.01027495	+0.01314913	+0.01273502
b_{16}	+0.00753657	+0.03289965	+0.04167011	+0.04149693
b_{17}	-0.16971825	-0.06637843	-0.05900642	-0.05710383
b_{18}	-0.20093998	+0.24668642	+0.32333713	+0.22097479
b_{19}	+0.20482656	+0.24300136	+0.36361838	+0.30001544
b_{20}	-2.02490050	-1.13183262	-1.25432243	-0.79213392
b_{21}	-0.60995291	-0.41267356	-0.20226090	-0.10538073
b_{22}	-0.86496204	-0.65002345	-0.96275522	-0.45677152

Table 12. Summary of linear correlation coefficients:

Snow courses versus Blacksmith Fork streamflow: (April 1 Snow data versus total annual streamflow)

Snow Courses	Franklin Basin	Mt. Logan	Tony Grove Lake	Monte Cristo	Dry Bread Pond	Garden City	Spring Hollow Upper	Spring* Hollow Lower	Tony* Grove R.S.
Coefficient	82.06%	81.2%	79.6%	79.15%	77.3%	77.3%	75.2%	67.3%	57.4%

* Eliminated in Analysis

Temperature versus Blacksmith Fork streamflow: (annual)

Logan temperature versus Blacksmith Fork streamflow linear correlation coefficient: 31.82%.

Precipitation versus Blacksmith Fork streamflow: (annual)

Precipitation	Richmond	Brigham City	Logan	Ogden
Correlation Coefficient	33.31%	28.08%	23.45%	5.4%

Logan River streamflow versus Blacksmith Fork River streamflow: (annual)

The linear correlation coefficient of Logan River streamflow versus Blacksmith Fork River streamflow: 91.58%

Table 13 . The linear regression equation and linear correlation coefficient of Mt. Logan snow course versus Tony Grove Lake snow course:

No. of Observation	Years	X: Mt. Logan (in.)	Y: Tony Grove L. (in.)	$x = X - \bar{X}$	$y = Y - \bar{Y}$
1	1924	25.8	31.8	- 2.78	- 1.90
2	1925	32.1	35.5	+ 3.52	+ 1.80
3	1926	22.0	21.9	- 6.58	-11.80
4	1927	40.8	43.5	+12.22	+ 9.80
5	1928	31.6	34.5	+ 3.02	+ 1.20
6	1929	35.0	41.7	+ 6.42	+ 8.00
7	1930	28.5	31.5	- 0.08	- 2.20
8	1931	13.4	14.9	-15.18	-18.80
9	1932	42.3	54.2	+13.72	+20.50
10	1933	28.4	38.4	- 0.18	+ 4.70
11	1934	18.8	19.2	- 9.78	-14.50
12	1935	27.9	29.1	- 0.68	- 4.60
13	1936	38.3	50.5	+ 9.72	+16.80
14	1937	27.4	32.5	- 1.18	- 1.20
15	1938	27.5	36.5	- 1.08	+ 2.80
16	1939	20.8	25.2	- 7.78	- 8.50
17	1940	23.5	27.0	- 5.08	- 6.70
18	1941	19.4	21.7	- 9.18	-12.00
19	1942	22.5	23.3	- 6.08	-10.40
20	1943	41.3	54.9	-12.72	+21.20
21	1944	17.8	20.5	-10.78	-13.20
22	1945	22.8	27.3	- 5.78	- 6.40
23	1946	36.1	37.4	+ 7.52	+ 3.70
24	1947	21.0	28.0	- 7.58	- 5.70
25	1951	37.4	52.0	+ 8.82	+18.30
26	1952	43.8	47.6	+15.22	+13.90
27	1953	26.0	35.5	- 2.58	+ 1.80
28	1954	27.9	27.5	- 0.68	- 6.20
Total		800.10	943.6	$\Sigma x^2 = 1824.49$	$\Sigma y^2 = 3281.02$
Mean		28.58	33.7		

The linear regression equation:

$$\hat{Y} = b\,X + a$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = 1.2621;\ a = -2.3706$$

$$\hat{Y} = 1.2621X - 2.3706$$

The linear correlation coefficient:

$$r^2 = \frac{\Sigma \hat{y}^2}{\Sigma y^2}\ ;\ r = 0.9411 = 94.11\%$$

$(\Sigma \hat{y}^2 = (\Sigma xy)^2 / \Sigma x^2$; and $\Sigma xy = 2302.678)$

Table 14. The linear regression equation and linear correlation coefficient of Garden City summit snow course versus Franklin Basin snow course data.

No. of Observations	Years	Y: Garden City (in.)	X: Franklin Basin (in.)	$y = Y - \bar{Y}$	$x = X - \bar{X}$
1	1931	4.4	14.9	-14.52	-11.67
2	1932	24.6	38.6	+ 5.68	+12.03
3	1933	18.2	28.2	- 0.72	+ 1.63
4	1934	4.3	12.6	-14.62	-13.97
5	1935	17.9	24.4	- 1.02	- 2.17
6	1936	33.9	39.7	+14.98	+13.13
7	1937	18.5	20.8	- 0.42	- 5.77
8	1938	20.4	24.9	+ 1.48	- 1.67
9	1939	16.7	20.4	- 2.22	- 6.17
10	1940	12.6	21.8	- 6.32	- 4.77
11	1941	12.8	15.6	- 6.12	-10.97
12	1942	14.1	17.8	- 4.82	- 8.77
13	1943	30.5	38.8	+11.58	+12.23
14	1944	15.6	20.2	- 3.32	- 6.37
15	1945	15.5	19.8	- 3.42	- 6.77
16	1946	26.1	30.2	+ 7.18	+ 3.63
17	1947	16.0	23.3	- 2.92	- 3.27
18	1948	15.4	26.5	- 3.52	- 0.07
19	1949	22.8	30.5	+ 3.88	+ 3.93
20	1950	28.9	41.3	+ 9.98	+14.73
21	1951	24.4	32.8	+ 5.48	+ 6.23
22	1952	26.6	40.2	+ 7.68	+13.63
23	1953	14.5	23.7	- 4.42	- 2.87
24	1954	19.5	23.3	+ 0.58	- 3.27
25	1955	14.6	23.8	- 4.32	- 2.77
26	1956	20.7	31.8	+ 1.78	+ 5.23
27	1957	21.3	31.6	+ 2.38	+ 5.03
Total		510.8	717.5	y^2= 1271.04	x^2 = 1746.11
Mean		18.92	26.57		

The linear regression equation:

$$\hat{Y} = b X + a$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = 0.7816; \quad a = 1.8475$$

$$\hat{Y} = 0.7816X + 1.8475$$

The linear correlation coefficient:

$$r^2 = \frac{\Sigma \hat{y}^2}{\Sigma y^2}; \quad r = 0.9161 = 91.61\%$$

$(\Sigma\hat{y}^2 = (\Sigma xy)^2 / \Sigma x^2$; and $\Sigma xy = 1364.786)$.

Table 15 . The linear regression equation and linear correlation coefficient of Monte Cristo snow course versus Franklin Basin snow course data.

No. of Obser- vations	Years	Y: Monte Cristo (in.)	X: Franklin Basin (in.)	$y = Y - \bar{Y}$	$x = X - \bar{X}$
1	1930	14.6	26.8	-10.28	- 0.44
2	1931	6.5	14.9	-18.38	-12.34
3	1932	20.2	38.6	- 4.68	+11.36
4	1936	39.6	39.7	+14.72	+12.46
5	1937	18.8	20.8	- 6.08	- 6.44
6	1938	30.7	24.9	+ 5.82	- 2.34
7	1939	20.3	20.4	- 4.58	- 6.84
8	1940	17.6	21.8	- 7.28	- 5.44
9	1941	16.4	15.6	- 8.48	-11.64
10	1942	18.2	17.8	- 6.68	- 9.44
11	1943	32.7	38.8	+ 7.82	+11.56
12	1944	18.3	20.2	- 6.58	- 7.04
13	1945	23.9	19.8	- 0.98	- 7.44
14	1946	30.6	32.0	+ 5.72	+ 4.76
15	1947	24.0	23.3	- 0.88	- 3.94
16	1948	22.0	26.5	- 2.88	- 0.74
17	1949	31.1	30.5	+ 6.22	+ 3.26
18	1950	36.0	41.3	+11.12	+14.06
19	1951	31.4	32.8	+ 6.52	+ 5.56
20	1952	39.2	40.2	+14.32	+12.96
21	1953	23.4	23.7	- 1.48	- 3.54
22	1954	22.3	23.3	- 2.58	- 3.94
23	1955	26.9	23.8	+ 2.02	- 3.44
24	1956	31.6	31.8	+ 6.72	+ 4.56
25	1957	25.7	31.6	+ 0.82	+ 4.36
Total		622.0	680.9	y^2= 1559.30	x^2 = 1548.72
Mean		24.88	27.24		

The linear regression equation:

$$\hat{Y} = b X + a$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = 0.7992 \; ; \; a = 3.1082$$

$$\hat{Y} = 0.7992 X + 3.1082$$

The linear correlation coefficient:

$$r^2 = \frac{\Sigma \hat{y}^2}{\Sigma y^2} = 0.6345$$

$$r = 0.7965 = 79.65\%$$

Table 16 . The linear regression equation and linear correlation coefficient of Dry Bread Pond snow course versus Franklin Basin snow course data.

No. of Obser- vations	Years	X: Dry Bread Pond (in.)	Y: Franklin Basin (in.)	$x = X - \bar{X}$	$y = Y - \bar{Y}$
1	1936	22.1	39.7	+ 3.25	+11.98
2	1937	13.3	20.8	- 5.55	- 6.92
3	1938	23.6	24.9	+ 4.75	- 2.82
4	1939	11.5	20.4	- 7.35	- 7.32
5	1940	10.7	21.8	- 8.15	- 5.92
6	1941	11.6	15.6	- 7.25	-12.12
7	1943	26.1	38.8	+ 7.25	+11.08
8	1944	12.9	20.2	- 5.95	- 7.52
9	1945	18.0	19.8	- 0.85	- 7.92
10	1946	18.7	30.2	- 0.15	+ 2.48
11	1947	16.0	23.3	- 2.85	- 4.42
12	1949	22.8	30.5	+ 3.95	+ 2.78
13	1950	27.0	41.3	+ 8.15	+13.58
14	1951	21.1	32.8	+ 2.25	+ 5.08
15	1952	31.3	40.2	+12.45	+12.48
16	1953	16.2	23.7	- 2.65	- 4.02
17	1954	14.7	23.3	- 4.15	- 4.42
18	1955	20.1	23.8	+ 1.25	- 3.92
19	1956	20.3	31.8	+ 1.45	+ 4.08
20	1957	19.0	31.6	+ 0.15	+ 3.88
Total		377.0	554.5	$\Sigma x^2 = 603.79$	$\Sigma y^2 = 1159.08$
Mean		18.85	27.72		

The linear regression equation:

$$\hat{Y} = b X + a$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = 1.72$$

$$a = - 4.68$$

$$\hat{Y} = 1.72 X - 4.68$$

The linear correlation coefficient:

$$r^2 = \frac{\Sigma \hat{y}^2}{\Sigma y^2} = 0.7345$$

$$r = 0.857 = 85.70\%$$

Table 17 . The linear regression equation and linear correlation coefficient of Logan River versus Blacksmith Fork River. (annual streamflow).

No. of Obser- vation	Years	Logan R. Y: 100 ac-ft.	Blacksmith X: 100 ac-ft.	$y = Y - \bar{Y}$	$x = X - \bar{X}$
1	1924	171.55	93.10	+ 1.49	+ 9.59
2	1925	171.47	87.20	+ 1.41	+ 3.69
3	1926	135.88	67.10	-34.18	-16.41
4	1927	187.00	88.10	+16.94	+ 4.59
5	1928	200.46	91.00	+30.40	+ 7.49
6	1929	182.47	88.50	+12.41	+ 4.99
7	1930	145.39	66.60	-24.67	-16.91
8	1931	92.84	43.20	-77.22	-40.31
9	1932	215.09	103.00	-45.03	+19.49
10	1933	170.85	74.70	+ 0.79	- 8.81
11	1934	90.99	42.16	-79.07	-41.35
12	1935	141.44	52.30	-28.62	-31.21
13	1936	236.54	110.20	+66.48	+26.69
14	1937	165.25	86.98	- 4.81	+ 3.47
15	1938	190.51	88.28	+20.45	+ 4.77
16	1939	137.11	63.08	-32.95	-20.43
17	1940	113.11	45.45	-56.95	-38.06
18	1941	97.25	38.35	-72.81	-45.16
19	1942	120.00	45.10	-50.06	-38.41
20	1943	209.41	84.81	+39.35	+ 1.30
21	1944	140.56	60.65	-29.50	-22.86
22	1945	159.03	71.92	-11.03	-11.59
23	1946	216.57	125.00	+46.51	+41.49
24	1947	174.01	57.55	+ 3.95	-25.96
25	1948	194.33	101.50	+24.27	+17.99
26	1949	183.57	98.47	+13.51	+14.96
27	1950	262.78	139.50	+92.72	+55.99
28	1951	237.41	136.90	+67.35	+53.39
29	1952	220.33	147.80	+50.27	+64.29
30	1953	170.40	90.96	+ 0.34	+ 7.45
31	1954	130.20	69.80	-39.86	-13.71
32	1955	132.49	69.63	-37.57	-13.88
33	1956	200.05	108.50	+29.99	+24.99
34	1957	185.59	102.10	+15.53	+18.59
Total		5,781.93	2,839.49	Σy^2; 60,497	Σx^2=26,783.17
Mean		$\bar{X}$: 170.06	$\bar{Y}$: 83.51		Σxy=36,864.87

Table 17 . (Continued)

The linear regression equation:

$$\hat{Y} = b\,X + a$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = 1.3764 \; ; \; a = 55.1152$$

$$\hat{Y} = 1.3764\,X + 55.1152$$

The linear correlation coefficient:

$$r^2 = \frac{\Sigma \hat{y}^2}{\Sigma y^2}; \; r = 0.9158 = 91.58\%$$

$$(\Sigma\hat{y}^2 = (\Sigma xy)^2 / \Sigma x^2 = 1{,}359{,}018{,}603.25/26{,}783.17 = 50{,}741.52)$$

Table 18 . The result of the analysis of variance of the four main variables* ---snow, temperature, precipitation, and streamflow in the streamflow forecasting equation for each month in percentiles of the "F" distribution.

Variables / Months	Snow water content	Temperature	Precipitation	Stream - flow
October	38	65	40	99.99
November	34	11	11	99.99
December	99.8	41	50	99.99
January	99.9	65	32	99.7
February	90	74	5	99.95
March	95	85	31	86
April	99.2	28	75	97.5
May	91	30	90	25
June	82	60	45	70
July	93	32	60	90
August	99.2	7	86	97
September	99.75	38	74	94

* For detail computation see Table (21) ---The analysis of variance of multiple regression model; this table serves as a summary.

Table 19 . The analysis of variance of multiple regression model.

October $R^2 = 0.9792$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	76.04523800		
Due to regression	22	74.46208866		
Snow	7	0.80320511	0.11474359	38
Temperature	5	0.87066756	0.17413351	65
Precipitation	5	0.54086117	0.10817223	40
Streamflow	5	32.13091303	6.42618261	99.99
Deviation from Regression	11	1.58314934	0.1439226667	

November $R^2 = 0.9757$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	52.27655300		
Due to regression	22	51.00706770		
Snow	7	0.60673467	0.08667638	34
Temperature	5	0.44130276	0.03720534	11
Precipitation	5	0.45275245	0.03817064	11
Streamflow	5	24.68096155	2.08090200	99.9
Deviation from Regression	11	1.26948530	0.11540775	

Table 19 . The analysis of variance of multiple regression model.

(Continued)

December $R^2 = 0.9504$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	47.87754400		
Due to Regression	22	45.50139148		
Snow	7	11.22018555	1.60288365	99.8
Temperature	5	0.83173372	0.16634674	41
Precipitation	5	1.00597198	0.20119439	50
Streamflow	5	18.43568762	3.68713752	99.99
Deviation from Regression	11	2.37615252	0.21601386	

January $R^2 = 0.9310$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	42.83494400		
Due to regression	22	39.88050474		
Snow	7	21.62769457	3.08967065	99.9
Temperature	5	1.60102277	0.32020455	65
Precipitation	5	0.89366680	0.17873336	32
Streamflow	5	10.54147502	2.10829500	99.7
Deviation from Regression	11	2.95443926	0.26858539	

Table 19 . The analysis of variance of multiple regression model. (Continued)

February $R^2 = 0.9424$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	32.42984700		
Due to regression	22	30.56151212		
Snow	7	2.91095713	0.41585102	90
Temperature	5	1.24768100	0.24953620	74
Precipitation	5	0.20103881	0.04020776	5
Streamflow	5	8.81846824	1.76369365	99.95
Deviation from Regression	11	1.86833488	0.16984862	

March $R^2 = 0.9080$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	64.71055300		
Due to regression	22	58.75469226		
Snow	7	12.44630305	1.77804329	95
Temperature	5	5.48597527	1.09719505	85
Precipitation	5	1.75504155	0.35100831	31
Streamflow	5	7.59030932	1.51806186	86
Deviation from Regression	11	5.95586074	0.54144188	

Table 19 . The analysis of variance of multiple regression model. (Continued)

April $R^2 = 0.9410$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	1750.45882700		
Due to regression	22	1647.24391723		
Snow	7	341.27075785	48.75296538	99.2
Temperature	5	26.78728370	5.35745674	28
Precipitation	5	70.55296270	14.11059254	75
Streamflow	5	195.18401039	39.03680208	97.5
Deviation from Regression	11	103.21490977	9.38317362	

May $R^2 = 0.8678$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	27.33834100		
Due to regression	22	23.72324289		
Snow	7	5.83171444	0.83310206	91
Temperature	5	0.99776132	0.19955226	30
Precipitation	5	3.84767808	0.76953562	90
Streamflow	5	0.85996400	0.17199280	25
Deviation from Regression	11	3.61509811	0.32864528	

Table 19 . The analysis of variance of multiple regression model.

(Continued)

<u>June</u> $R^2 = 0.8910$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1V_2)$
Total	33	470.22974400		
Due to regression	22	418.97880991		
Snow	7	59.93941167	8.56277309	82
Temperature	5	25.36634625	5.07326925	60
Precipitation	5	19.55518749	3.91103749	45
Streamflow	5	30.54401076	6.10880215	70
Deviation from Regression	11	51.25093409	4.65917582	

<u>July</u> $R^2 = 0.9270$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	184.77881200		
Due to regression	22	171.28323655		
Snow	7	24.98301906	3.56900272	93
Temperature	5	4.01426490	0.80285298	32
Precipitation	5	6.65927254	1.33185451	60
Streamflow	5	14.49918519	2.89983704	90
Deviation from Regression	11	13.49557545	1.22687050	

Table 19 . The analysis of variance of multiple regression model.

(Continued)

<u>August</u> $R^2 = 0.9469$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1 V_2)$
Total	33	126.11004700		
Due to regression	22	119.41828553		
Snow	7	25.33271960	3.11742500	99.2
Temperature	5	0.77676228	0.15535246	7
Precipitation	5	6.18004939	1.23600988	86
Streamflow	5	12.03248290	2.40649658	97
Deviation from Regression	11	6.69176147	0.60834195	

<u>September</u> $R^2 = 0.9413$

Sources	df	Sum of Square	Mean of Square	Percentiles $F(V_1,V_2)$
Total	33	84.54255600		
Due to regression	22	79.57818533		
Snow	7	25.27151883	3.61021695	99.75
Temperature	5	1.65340643	0.33068129	38
Precipitation	5	3.33984899	0.66796980	74
Streamflow	5	6.82864536	1.36572907	94
Deviation from Regression	11	4.96437067	0.45130642	

Table 20 . The results of the analysis of variance of the individual variables in the forecasting equation for each month in terms of the percentiles of the F--distribution:

Variables	October	November	December	January	February	March
Franklin B.	85	60	45	50	90	70
Mt. Logan	40	75	95	95	45	70
Tony Grove L.	80	50	35	45	65	65
Monte Cristo	80	60	1	75	80	70
Dry Bread P.	65	75	97	99	99.5	97.5
Garden City	80	35	45	20	70	25
Spring Hollow U.	30	70	99.5	99	90	97.5
Mean Temperature	96	80	35	85	75	7.5
cosθ	50	70	80	75	75	70
sinθ	75	60	15	65	93	55
cos2θ	1.5	65	25	2.5	88	97.5
sin2θ	60	55	10	40	70	90
Mean Precip.	1	0.5	45	25	40	60
cosθ	30	2.5	5	10	5	50
sinθ	30	2.5	2.5	35	55	10
cos2θ	30	55	15	2.5	40	85
sin2θ	80	80	85	80	10	50
Mean Streamflow	99.5	99.5	99.5	97.5	97	75
cosθ	85	80	10	10	15	35
sinθ	92	85	40	40	50	55
cos2θ	25	35	75	70	90	80
sin2θ	2.5	5	40	90	65	60

Table 20 . The results of the analysis of variance of the individual variables in the forecasting equation for each month in terms of the percentiles of the F -distribution: (continued)

Variables	April	May	June	July	August	September
Franklin Basin	25	75	70	70	65	70
Mt. Logan	60	75	45	70	85	80
Tony Grove L.	35	40	50	35	40	35
Monte Cristo	70	75	85	85	80	90
Dry Bread Pond	35	5	45	45	15	45
Garden City	70	25	80	60	50	65
Spring Hollow U.	65	35	25	35	70	50
Mean Temperature	70	35	80	70	70	85
$\cos\theta$	15	20	70	70	60	50
$\sin\theta$	85	65	35	15	25	55
$\cos 2\theta$	20	25	65	5	15	8
$\sin 2\theta$	35	10	60	65	40	55
Mean Precip.	90	45	75	85	85	80
$\cos\theta$	20	75	25	35	70	30
$\sin\theta$	70	65	15	5	15	15
$\cos 2\theta$	75	70	5	25	50	60
$\sin 2\theta$	10	85	70	60	70	80
Mean Stream-flow	80	5	20	35	70	60
$\cos\theta$	90	70	15	25	65	60
$\sin\theta$	97.5	85	80	85	95	90
$\cos 2\theta$	25	55	30	35	25	15
$\sin 2\theta$	85	60	35	50	80	55

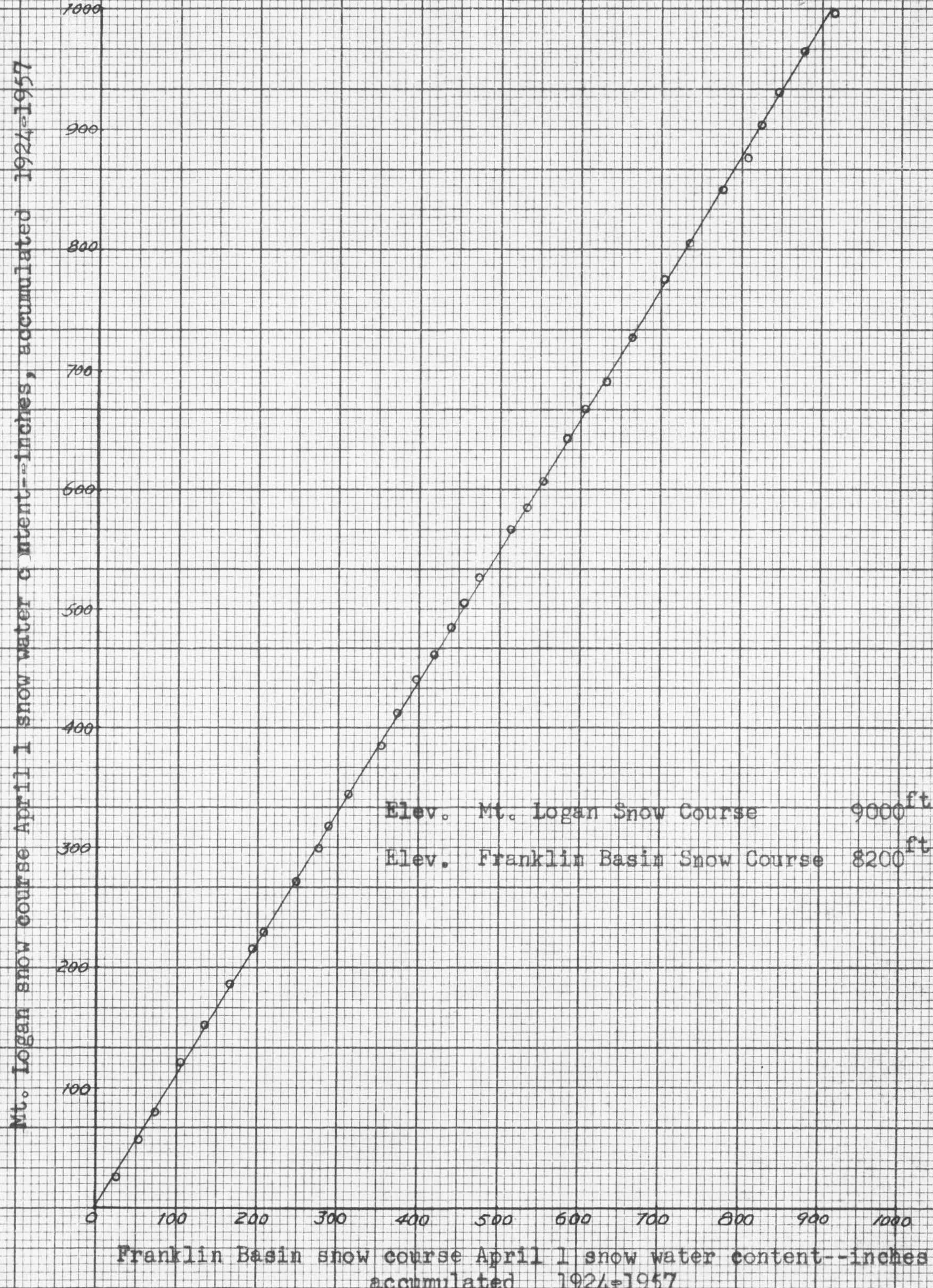

Figure 1. Double mass curve of Mt. Logan snow course data versus Franklin Basin snow course data.

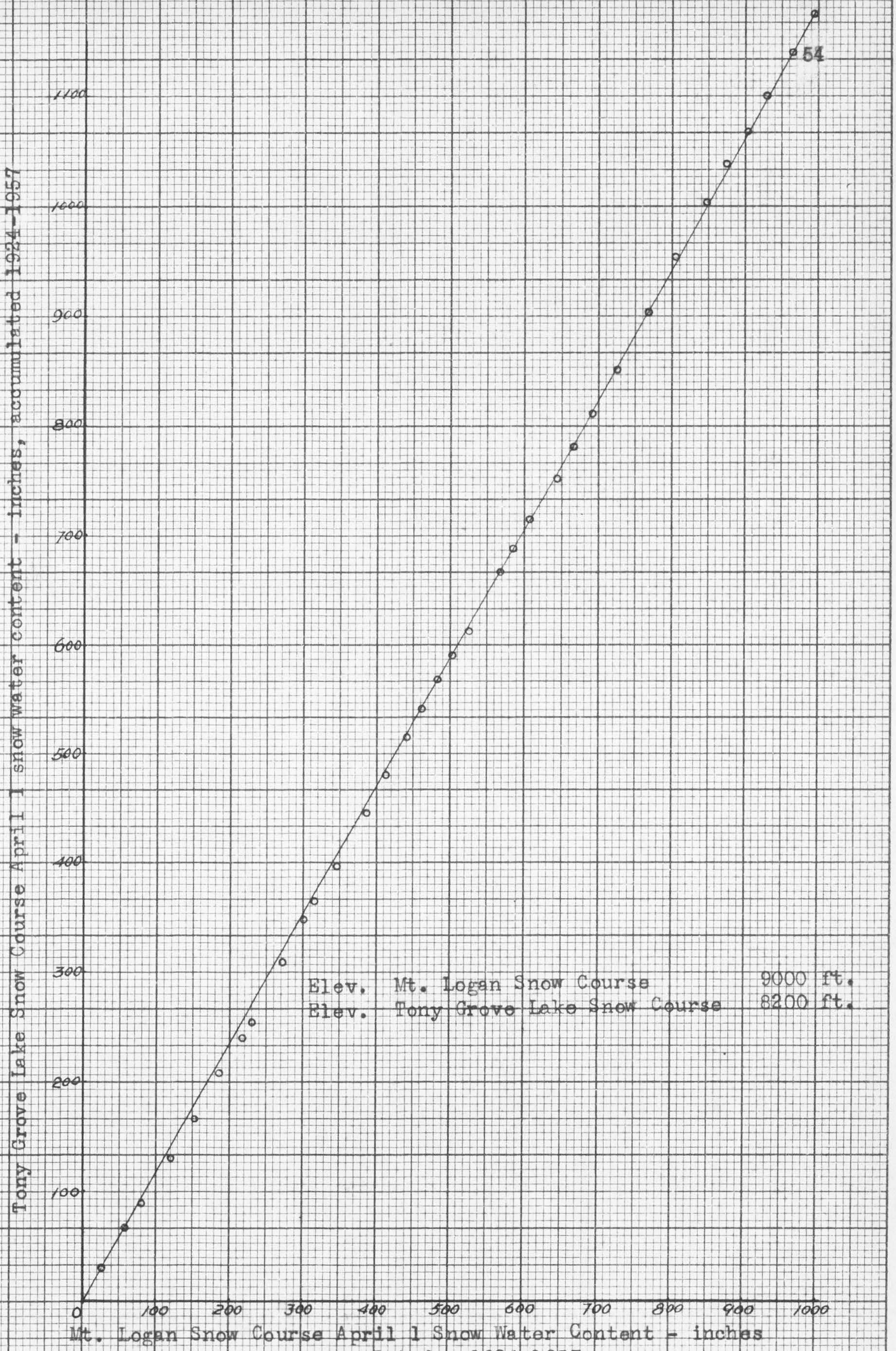

Figure 2. Double mass curve of Mt. Logan Snow Course data versus Tony Grove Lake Snow Course data.

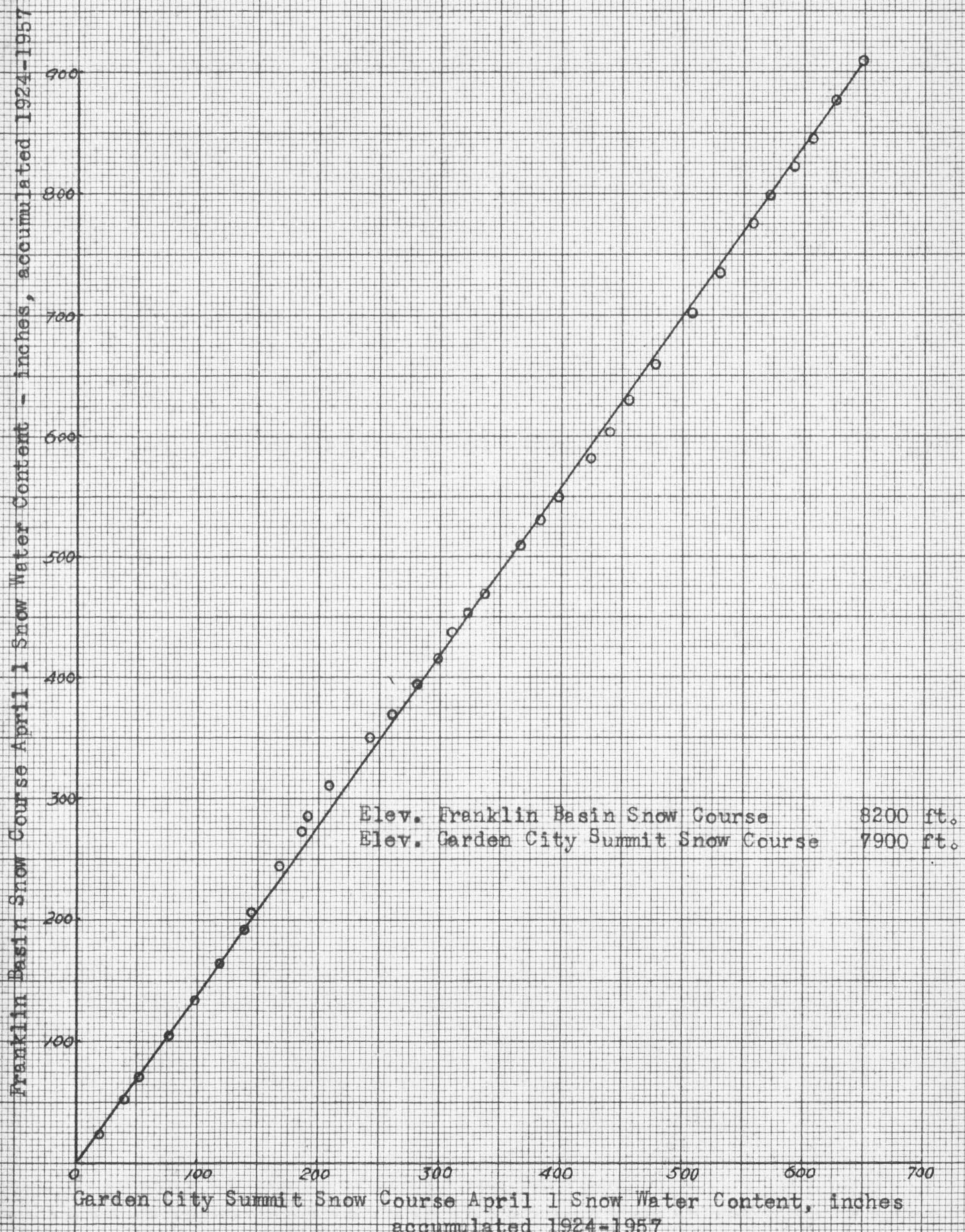

Figure 3. Double mass curve of Franklin Basin Snow Course data versus Garden City Summit Snow Course data.

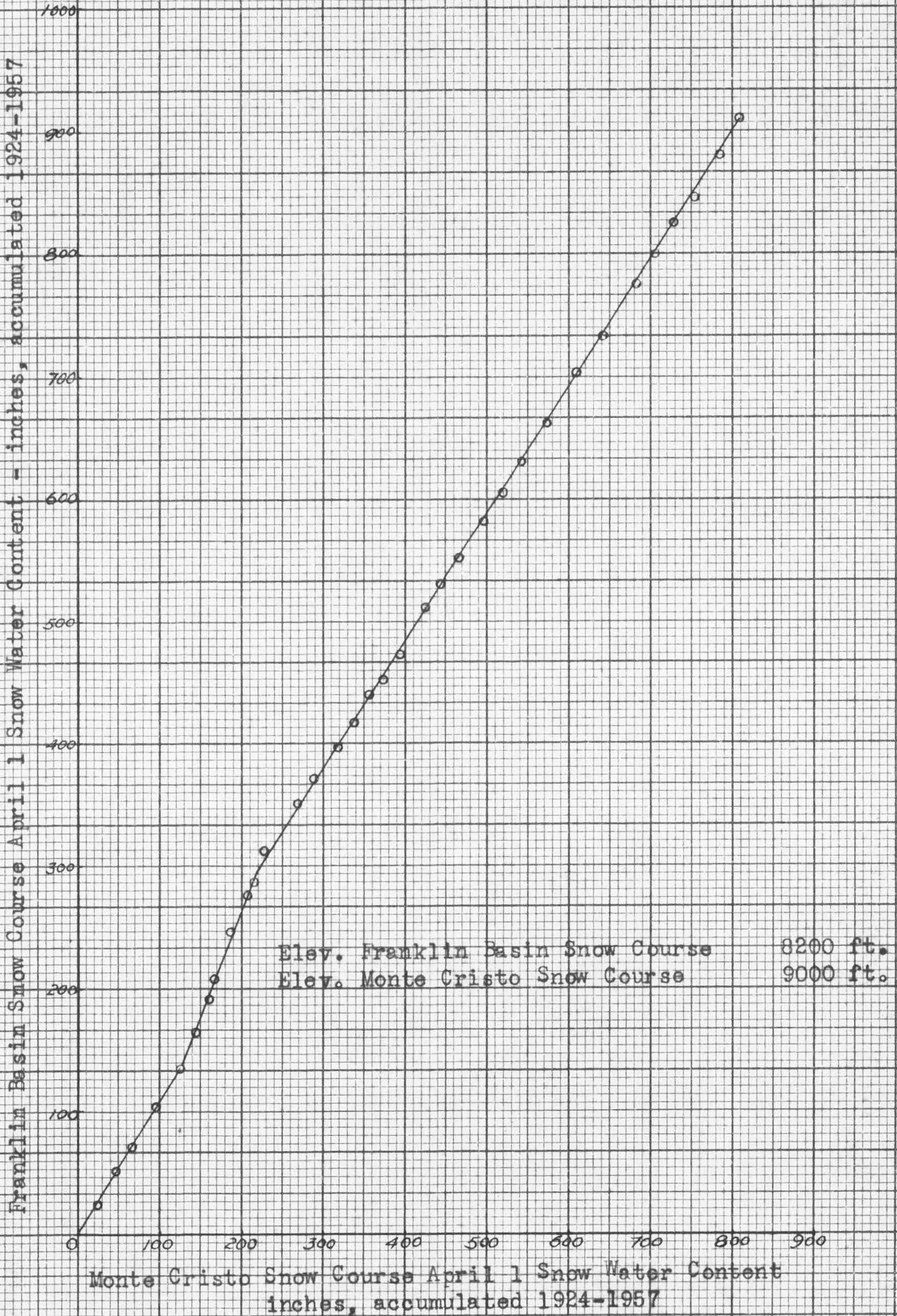

Figure 4. Double mass curve of Franklin Basin Snow Course data versus Monte Cristo Snow Course data.

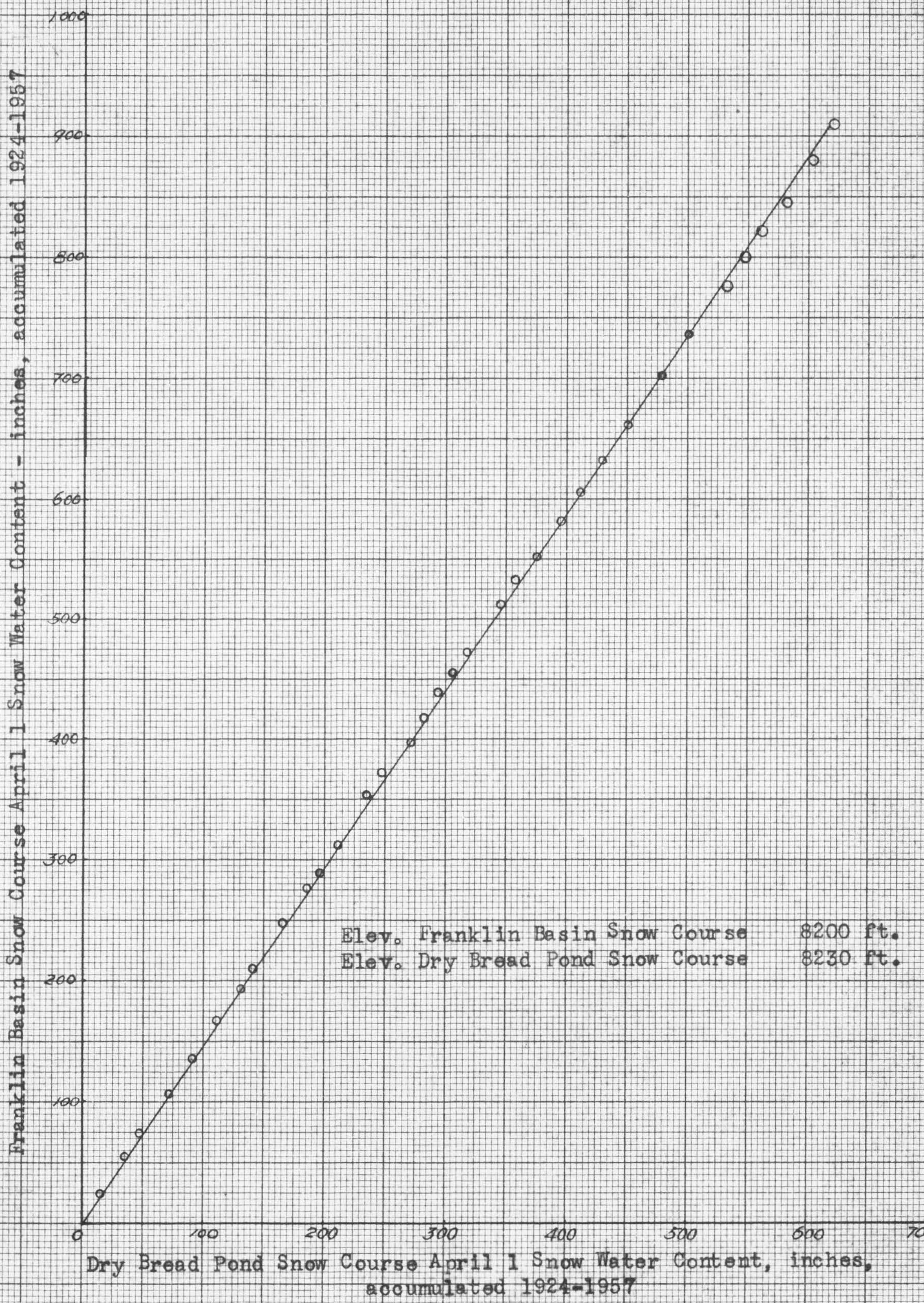

Figure 5. Double mass curve of Franklin Basin Snow Course data Versus Dry Bread Pond Snow Course data.

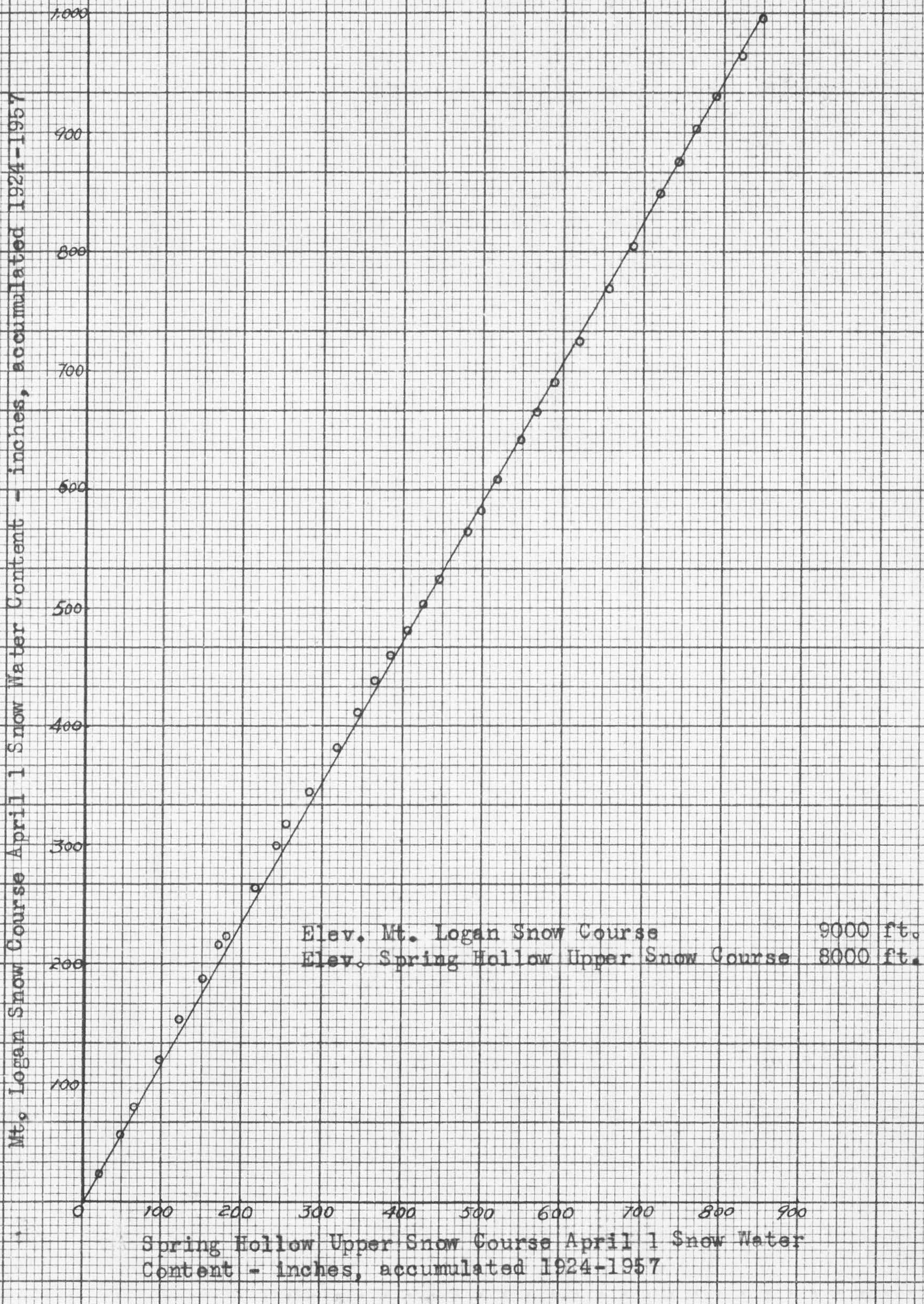

Figure 6. Double mass curve of Mt. Logan Snow Course data Versus Spring Hollow Upper Snow Course data.

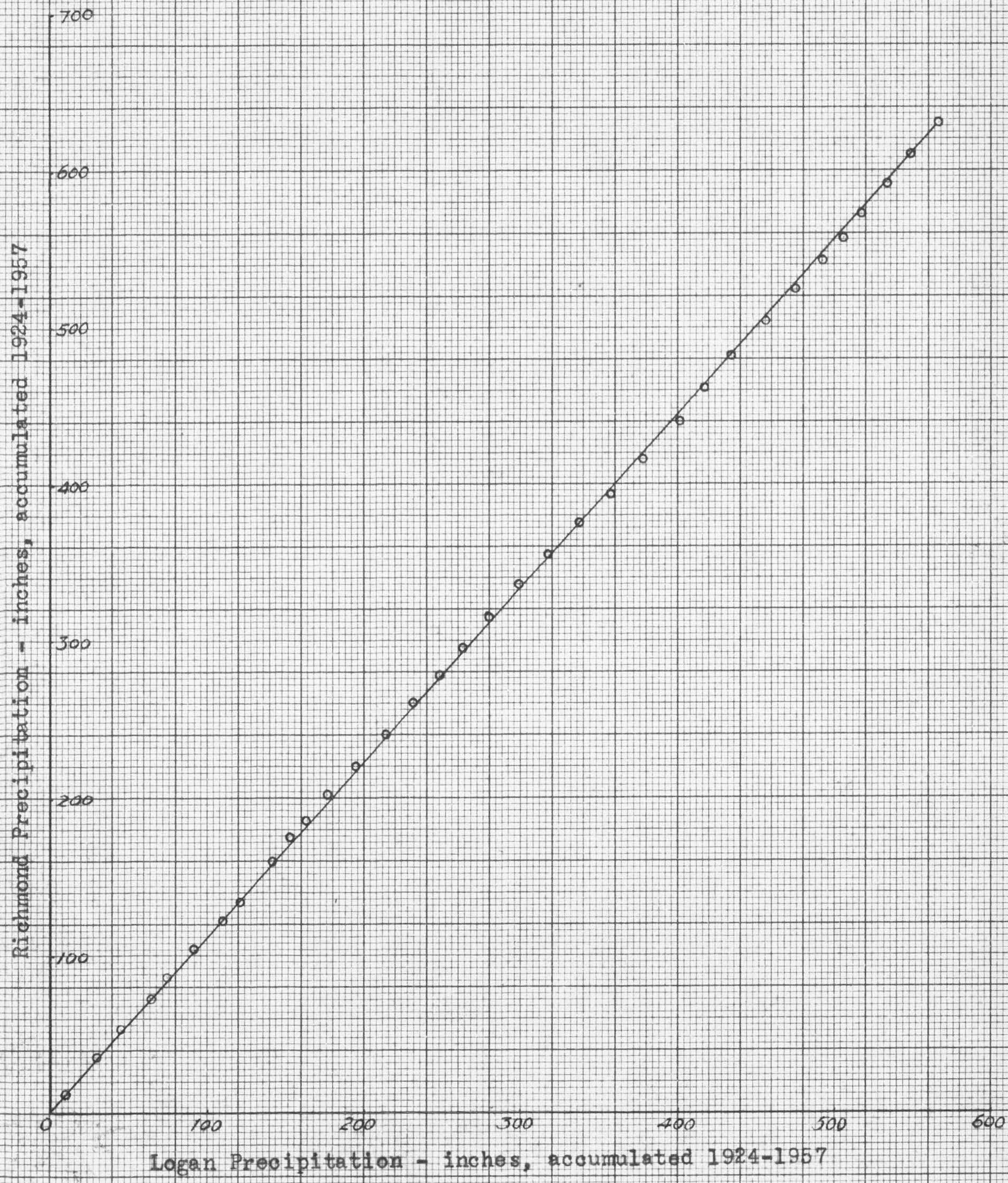

Figure 7. Double mass curve of Richmond precipitation data Versus Logan Precipitation data.

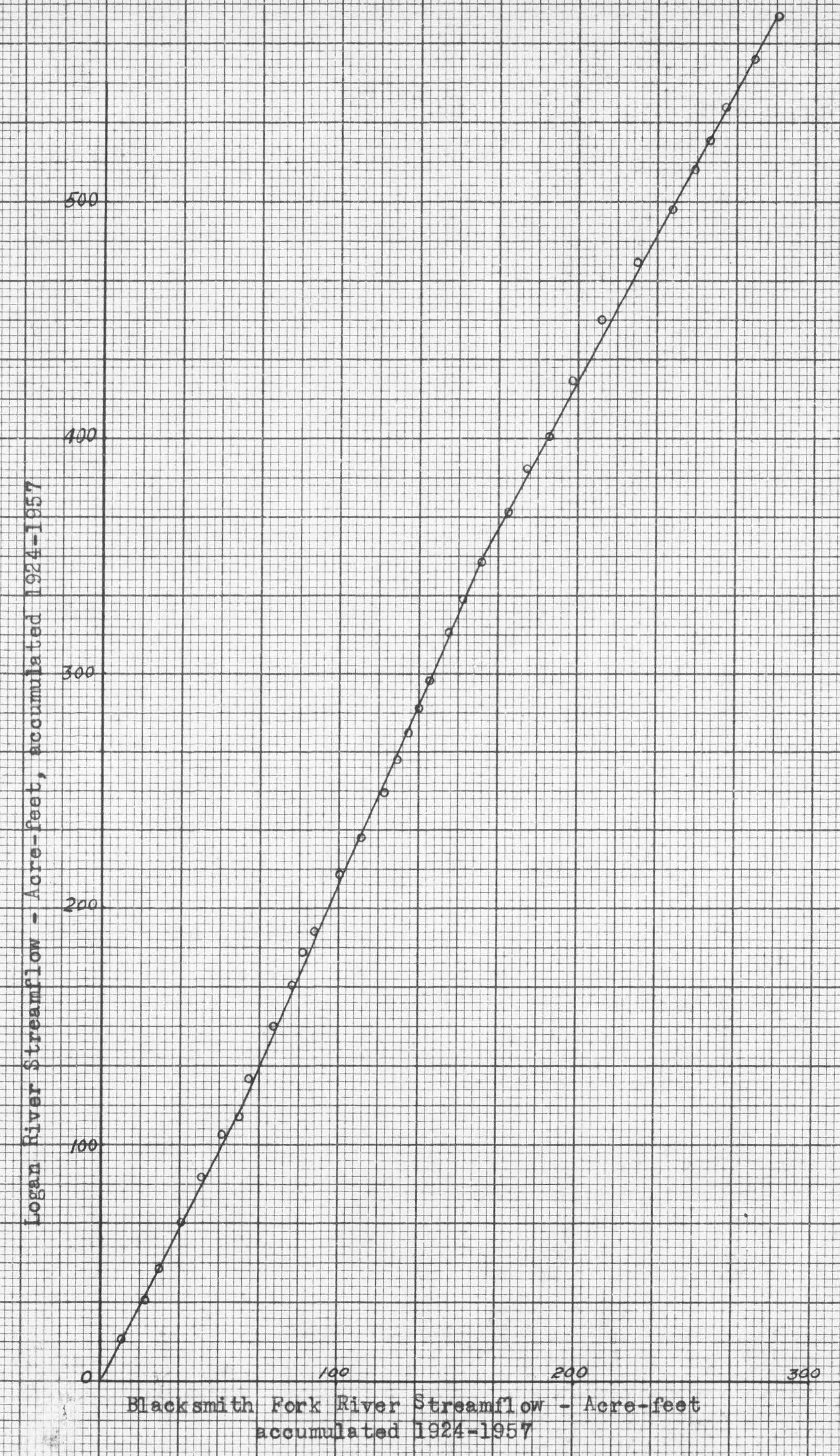

Figure 8. Double mass curve of Logan River Streamflow data Versus Blacksmith Fork River Streamflow data.